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THE LIMING OF SOILS.

BY

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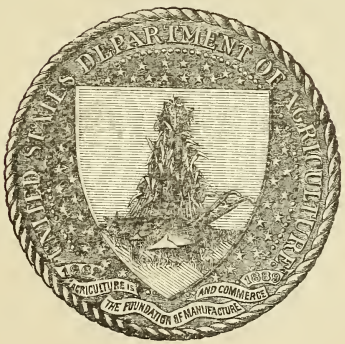

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., April 15, 1898.

Sir: I have the honor to transmit herewith an article on the liming of soils, by H. J. Wheeler, Ph. D., chemist of the Rhode Island Agricultural Experiment Station. There has been in recent years a renewal of interest in problems relating to the use of lime for the improvement of soils. This is due in large measure to the work of the experiment stations. Among others, the investigations at the Rhode Island Station, under the supervision of the author of this article, have shown the great benefit which follows the use of lime on soils under proper conditions. The article is submitted with the recommendation that it be published as a Farmers' Bulletin.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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THE LIMING OF SOILS.

THE USE OF LIME FOR IMPROVING SOILS.

The recognition of the agricultural value of certain forms of lime is not new, and it appears probable from the writings of Pliny that liming was practiced by the Romans more than two thousand years ago. In England, Germany, France, and other European countries the application of lime in various forms has been and is still practiced extensively.

Dehérain states that certain regions of France have undergone a veritable agricultural transformation owing to the use of lime and marl. Müntz and Girard assert that more than one-fifth of the area of France is of granitic origin, and that when the soils are supplied with lime and phosphoric acid, which they lack, they undergo a complete transformation.

In certain sections of Germany carbonate of lime in the form of marl plays an important part in maintaining the fertility of the soil. According to Wicke, the yields in certain districts of Germany have been quadrupled by the employment of marl, and many plants whose cultivation was previously impossible can be grown at a profit after the soil has been limed.

That eminently practical as well as scientific agriculturist, Schultz, of Lupitz, has demonstrated the immense value of marl in developing the productiveness of the light soil of that section of Germany. By its use, in connection with abundant potash and phosphoric acid, he has caused leguminous crops to gather from the air large stores of nitrogen, thus making it possible to cultivate the light soils at a profit.

Haxton, in a prize essay "On light land farming," mentions a number of siliceous, sandy soils in various parts of England which are greatly benefited by liming, and in speaking of the granite formation in Scotland asserts that "the whole of the granite soils are deficient in lime, and the first step toward their improvement, after being drained, is to apply this substance in a hot or caustic state."

Ruffin is perhaps the most prominent of the earlier writers who called attention to the agricultural use of lime in the United States. As early as 1818, and later in 1821, articles on the subject were contributed by him to the American Farmer, and in 1832 appeared the first edition of his well-known work on "Calcareous manures." He cites many instances showing the benefit derived from calcium carbonate when applied in the form of marl to his own and other Virginia estates.

In certain parts of Pennsylvania and New York lime has long been considered one of the essentials in wheat production. The beneficial

effect of liming has been demonstrated in other parts of the United States, especially in the eastern portion, but, as Roberts states, probably 99 per cent of the arable soil of the United States has never been limed. The work of some of the experiment stations, notably that of Rhode Island, has shown that soils which respond profitably to liming, either on account of their acid condition or of a deficiency of lime, are very widely distributed.

DIRECT MANURIAL ACTION OF LIME.

Authorities seem to agree that lime is necessary to the plant, and if it be wholly lacking in soils, even though an abundance of all the other essential elements is present, it can not develop normally. Just as a chain is useless with a missing link, so the plant can not grow if one of the essential elements of plant food is lacking. As already stated, lime has been found to be especially deficient in soils derived from granite. It is also often true of soils derived from mica-schist and sandstone. Fortunately, however, many soils are well provided with lime by nature and it is seldom or never necessary for those who cultivate them to resort to liming. It would be just as irrational to apply lime where it is not needed as to omit it where it is required, and hence arises the necessity of ascertaining the needs of particular soils in this respect.

The method usually resorted to for ascertaining the amount of lime in soils is to treat them with some strong mineral acid (usually hydrochloric) and determine the amount of lime which is thus dissolved. Some writers state that if only one-half of 1 per cent is thus shown to be present immediate resort to liming is desirable; others set the amount higher, and some seem to prefer to have present as much as 1 per cent. It is possible that a soil may contain considerable quantities of lime thus removable by acid and yet in actual practice show much benefit from liming. As a matter of fact, soils of limestone origin sometimes show benefit from liming. This seems to be due to the fact that a considerable amount of lime compounds, soluble in hydrochloric acid, may exist, and the soil be nevertheless so charged with inert organic matter or so acid that the profitable production of certain crops is an impossibility.

The fact that beets of all kinds make a ready response to liming on soils which are deficient in lime may be utilized as the basis for a practical and reliable method of testing the lime requirements of the soil. For this purpose lay out two plats of land, each about 12 by 30 feet, manure each of the plats with like amounts of a fertilizer containing potash, phosphoric acid, and nitrogen, and apply lime to one of the plats at the rate of from 1 to 2½ tons per acre (40 pounds per plat would be approximately 2½ tons per acre). A comparison of the growth and yields on the two plats will furnish a safe means of judging whether the soil will respond profitably to applications of lime.

CHEMICAL ACTION OF LIME ON SOILS.

Lime is said to take the place of potash in certain chemical compounds which exist in soils, thus liberating the potash and placing it at the disposal of plants. In this particular, gypsum (land plaster or calcium sulphate) is believed to act more energetically than carbonate of lime, air-slacked, or water-slacked lime.

When soluble phosphates are applied to soils deficient in lime and magnesia the phosphoric acid combines with the iron and alumina of the soil to form compounds which are not readily utilized by plants. If, however, the soil is fairly well supplied with lime and magnesia this transformation is retarded so that the plant is afforded an opportunity to utilize much of the phosphoric acid before it becomes unassimilable. If a soil containing a certain inert phosphate of iron is heavily limed, it is believed that this phosphate will be changed into a form which the plant can utilize. Lime may therefore not only help to maintain fresh applications of phosphoric acid for a long time in assimilable condition, but it may, if applied in sufficient quantity, help to unlock stores of phosphoric acid which plants would otherwise be unable to use.

Hilgard has abundantly demonstrated the great value of gypsum (land plaster) in renovating "alkali" soils in the arid portions of the United States. Wherever too much sodium carbonate (black alkali) is the cause of the unproductive condition of the soil the gypsum reacts with it, producing sodium sulphate and carbonate of lime, whereby the alkalinity may be sufficiently reduced to render possible the profitable production of crops.

In case protosulphate of iron and certain other poisonous compounds are present in soils, liming so changes them as to render them harmless to plants.

When the remains of plants undergo decay upon soils deficient in carbonates of lime and magnesia, acid or sour humus is liable to be produced, which is particularly noxious to most agricultural plants, though perhaps helpful to the growth of lupines and a few others. Such conditions are liable to occur even in upland and naturally well drained soils. Liming is in all such cases an effectual and probably the most economical remedy.

PHYSICAL EFFECTS OF LIMING.

Many clay soils when wet by rains are not porous enough to allow the water to pass through them with sufficient rapidity, in consequence of which they become water-logged and the air which is necessary for the healthful development of plant roots within the soil is excluded. In times of drought, also, such soils cake readily, thus becoming more difficult to till and less adapted physically to the growth of plants. Liming is an effective preventive or remedy for all of these unfavorable conditions. Upon certain loamy soils containing considerable clay

liming often renders the surface more friable and less liable to form a crust upon drying.

The improvement of drainage brought about by liming is one of the most effective means of preventing surface washing. When heavy rains occur on limed soils the water sinks into the soil instead of rushing over the surface, carrying the fine soil particles with it and thus producing galls and washes.

Soils which are composed of siliceous sand are frequently benefited by being rendered more compact by liming. On such soils carbonate of lime is preferable to air or water slacked lime, owing to the caustic nature of the latter, and the best material to employ where it is obtainable is a clay marl containing a fair amount of carbonate of lime. The clay as well as the lime tends to materially improve the physical condition of the soil. It should also be the aim to increase the amount of organic matter in such soils by the use of muck and stable manures, or by the occasional plowing under of a green crop or of sward.

THE EFFECT OF LIME ON THE ACTION OF MICROSCOPIC ORGANISMS IN THE SOIL.

Many important changes are produced in the soil by organisms so small that they can only be observed by the aid of the most powerful microscopes. Some of the changes of this character in which lime plays an important part are the following:

(1) The change of ammonia and of nitrogen in organic matter, such as blood, meat, fish, tankage, plants, etc., into nitrates, the form in which it is chiefly assimilated by most cultivated plants. This is known as the process of nitrification and is promoted by the presence of lime in soils.

(2) The decomposition of organic matter in muck and other soils. In this process the production of carbonic acid is much accelerated by the use of lime. This carbonic acid in turn so acts upon the inert plant food of the soil as to make it more quickly available to plants. The indirect result, therefore, is to help the plant to draw more potash, phosphoric acid, etc., from the soil than would otherwise be possible.

(3) The utilization of atmospheric nitrogen by certain of the leguminous plants (notably the clovers), particularly upon sour soils, is facilitated by the application of lime.

LIMING SOMETIMES INJURIOUS.

Excessive amounts of lime, especially on light soils, may have an injurious action. This is particularly true of freshly slacked lime upon light sandy soils containing but small amounts of organic matter. It hastens unduly the decomposition of the organic matter, and thus renders the soil more open and less retentive of fertilizers and moisture than before. If freshly slacked lime must be used upon such soils it should be applied in small amounts and at not too frequent intervals.

As stated heretofore, clay marls are much better adapted than other forms of lime for the improvement of such soils. In lieu of such marl, wood ashes or lime which has been exposed to the action of the air for a long time, might be preferable to lime freshly prepared.

Before the advent of complete fertilizers it was a common adage that liming "makes rich fathers and poor sons." If lime is used alone it serves to liberate potash, nitrogen, and perhaps sometimes phosphoric acid, and the extra drain of increased crops on the soil naturally leaves it finally in a worse condition than at the outset. In other cases, the soil reverts after many years to its former state of unproductiveness without appreciable injury. Continued success from liming can only be obtained by the use of the other essential manurial fertilizing constituents in connection with the lime. Few, if any, cases are on record where soils originally in need of lime have failed to continue to give good results from liming when care was taken to maintain a supply of the other essential constituents and where lime was applied in moderate amounts.

There are impure forms of lime which, after burning, will harden like cement, and which on this account may have an injurious action upon the soil. If pulverized without burning, they are capable of yielding good results.

Dolomitic (magnesian) limestone contains widely varying percentages of magnesia and lime. Such stone if containing high percentages of magnesia may sometimes prove objectionable if used exclusively. When such material is applied to soils the lime is removed by crops and the drainage water more rapidly than the magnesia, and if the lime thus becomes practically exhausted the residual magnesia in the soil may have an injurious action. This can, however, be overcome by adding more lime. Rather than use such lime for long periods of years on the same land, it would be preferable to alternate frequently with lime containing little or no magnesia.

Some magnesia in lime is by no means objectionable, and may, on certain soils, prove positively beneficial.

PLANTS BENEFITED BY LIMING.

The following are some of the plants which, in experiments on acid soils at the Rhode Island Experiment Station, have shown marked benefit from the use of lime: Spinach, lettuce, beets (all kinds), gumbo (okra), salsify (vegetable oyster), celery, onion, parsnip, cauliflower, cucumber, eggplant, cantaloupe, asparagus, kohl-rabi, cabbage, dandelion, Swedish turnip, pepper, pea, peanut, martynia, tobacco, sorghum, alfalfa, clover, barley, wheat, oats, timothy, and Kentucky blue grass. Not only was the crop greater, but in many instances it was ready for market much earlier where the soil was limed. There was at least two weeks' difference in kohl-rabi in this respect. Tobacco not only made a much better growth when limed, but the ash was much lighter in color.

PLANTS INJURED BY LIMING.

A few plants have shown considerable injury from the use of lime; these are, serradella, watermelon, blue lupine, and common sorrel (*Rumex acetosella*). Only one season's results are on record with serradella, but the other plants have been tested for several seasons with the same result. Extensive European tests have also shown the lupine to be injured by liming. Though common sorrel is directly injured by liming, the chief effect of lime in ridding land from sorrel seems to be attributable to its favoring the growth of cultivated plants to such an extent that the sorrel is smothered by them.

PLANTS NEARLY INDIFFERENT TO LIMING.

Standing between the two groups of plants given above are a number which when they are supplied with all of the nitrogen they require in a readily assimilable form, such as nitrate of soda, show little or no benefit from liming. Among those are Indian corn, common millet, Hungarian, golden millet, rye, potatoes, carrots, Rhode Island bent (grass), and redtop (grass). On a very acid or sour soil even those plants would be benefited by lime by virtue of its helping to change the nitrogen into readily assimilable nitrates, provided sulphate of ammonia, blood, tankage, fish, cotton-seed meal, plant roots, etc., were present as sources of nitrogen.

The above tests, carried out at the Rhode Island Station, were made in the field upon a soil well supplied with superphosphate, muriate of potash, and nitrate of soda, and also in some of the later tests with magnesia.

INFLUENCE OF LIME UPON SOME PLANT DISEASES.

Potato scab.—It has been shown that carbonate of lime and such other forms of lime as are changed into the carbonate by decomposition within the soil all tend to favor the production of potato scab, provided the germs of the disease are already in the soil or are introduced into it on the seed tubers. This seems to be due to the fact that the lime makes the soil alkaline, or to some influence which the combined carbonic acid of the carbonate of lime exerts upon the development of the fungus.

In view of this unfavorable action of lime, caution should be observed in liming potato fields. If such fields are to receive the treatment, they should be limed, if possible, some time before potatoes are to be grown. The seed tubers employed should also be treated before planting with corrosive sublimate solution or some other effective fungicide.[1]

Club root.—Many writers seem to agree that liming is capable of lessening materially the injury to turnips, cabbages, etc., caused by the disease known as "finger-and-toe" and "club root." English writers assert that by resort to liming excellent crops of turnips have been

[1] For method of treatment see U. S. Dept. Agr., Farmers' Bul. 56 (Experiment Station Work—I).

produced where without it the crop was a failure owing to the attacks of the disease.

Other diseases.—The effect of lime in different forms has been tested, with not entirely conclusive results, on various other diseases, including cranberry and sweet potato diseases, and a root disease of alfalfa (*Rhizoctonia medicaginis*). Slacked lime was found to be effective in reducing soil rot of sweet potatoes, and quicklime in checking or preventing the root disease of alfalfa.

HOW OFTEN SHOULD LIMING BE PRACTICED?

The frequency with which liming should be practiced depends upon several conditions; for example, upon the character of the soil, the quantity of lime employed in each application, the number of years involved in a rotation, the plants to be grown and their order of succession. Formerly, in England, large quantities of lime were applied at somewhat rare intervals, but there and elsewhere at the present time the preferable practice seems to be to use small amounts and apply it more frequently. As a general rule it may be stated that from half a ton to one and a half tons of lime per acre applied every five to six years is sufficient. There may exist extreme soils requiring either more or less than these amounts. If soils which are quite acid and have not previously been limed are to be seeded, with the intention of allowing them to remain in grass for several years, as much as two or three tons of lime per acre may be advisable. Only very extreme cases would call for larger applications. If in a rotation covering a considerable number of years two crops especially benefited by lime are introduced at about equidistant intervals of time, it may be advisable to lime twice in the course of the rotation, each time just prior to their introduction. In renovating acid pastures and meadows it is usually preferable to apply a fair amount of lime upon the furrows when they are first plowed so that this may be thoroughly mixed with the soil by subsequent plowing and harrowing, and just prior to seeding to grass make another generous application. By such treatment, provided the other essential fertilizing ingredients are employed, a good stand of clover, Kentucky blue grass, timothy and other grasses may be obtained where in many instances they were formerly partial or total failures and where only redtop, Rhode Island bent, and grasses having similar soil adaptability could be grown. Where land is kept in grass for a number of consecutive years, top-dressing with lime may be advisable, particularly if ordinary commercial fertilizers are employed in lieu of stable manure.

WHEN TO APPLY LIME.

Lime in the form of carbonate of lime as in marl, wood ashes, etc., can usually be applied with safety in the spring or at any other season of the year, but autumn is always the safest time to apply caustic or

slacked lime. The latter form changes gradually into carbonate of lime, which is not caustic, upon exposure to the air, but usually a considerable quantity has not yet reached that stage, when applied, and it may in consequence act too energetically. This is particularly true if the soil is light and sandy, and if plants, which are but little helped by lime, are employed. On very acid soils, particularly such as contain much humus, there is little or no danger from applying reasonable quantities of lime in the spring. If caustic or slacked lime is applied in excessive amounts it may not only injure plants directly but also indirectly by rendering the texture of the soil unfavorable; it may also make the soil temporarily so alkaline as to interfere with the activity of the organisms which transform ammonia into readily assimilable nitrates. Injury thus arising can not ordinarily be of long duration, for the reason that the carbonic acid of the soil changes the caustic lime rapidly into carbonate of lime, and thus the alkalinity of the soil is soon reduced.

HOW TO APPLY LIME.

Some writers recommend that upon old mossy meadows and pastures lime should be applied to the surface before plowing, in order that it may help to quickly decompose the organic matter. The chief objection to this procedure is that the lime does not become well incorporated with the soil, and since some of it is turned to the bottom of the furrow and its tendency at all times is to work downward, it may be quickly carried not only away from the surface soil, but also from the reach of plants. The practice of liming such soils immediately after plowing and then thoroughly harrowing has been attended by excellent results. This is particularly the case provided a second application is made in a similar manner, just previous to reseeding. Under such a plan some lime becomes intimately mixed with the entire mass of soil by the operations of tillage, and finally a considerable amount is left near the surface, thus accomplishing two important objects.

In some sections where marl is extensively used it is spread upon the surface and plowed under, turning a furrow about 2 inches deep. The more common method where marling is practiced is to plow the land and then cart on the marl, dumping it in heaps at such intervals that it can be spread conveniently with a shovel. If the marl is not sufficiently fine and is of such a nature that it crumbles upon exposure to the air, the heaps may be allowed to remain for some time before spreading, and still further time may be allowed to elapse before the operation of harrowing is begun. Sometimes a "clod crusher" or "bush harrow" may be employed to advantage to break up the lumps before harrowing. A most important point to be observed in applying lime in all of its forms is to mix it with the soil as thoroughly as possible, the finer the particles the better being the result.

Lime which is already slacked may be spread upon the soil directly from wagons or carts, or dumped in heaps and then spread with a shovel, though the most satisfactory plan in such cases is to employ an ordinary grain drill with fertilizer attachment or a lime spreader. In the use of such spreaders it is generally advisable to attach some burlap or old bagging to the sides and rear of the machine in such a way that it will trail upon the ground. If the machine is so equipped and the burlap is weighted with a piece of wood at the rear, much of the unpleasantness connected with spreading lime is avoided. For those familiar with the nature of lime and its use it is unnecessary to state that it is well, if possible, to apply it on a quiet day. The eyes may be protected by glasses and the nostrils and mouth by devices used by those who run threshing machines.

The only other form of lime in connection with the application of which any particular difficulty might be encountered is quick or burned lime. Where only small quantities of caustic lime are to be used it is frequently immersed for a moment in water, in a basket, and emptied into a wagon body. The following day it will be slacked sufficiently for use. Where larger quantities are used, and a lime spreader is at hand, the lime is sometimes water slacked in large piles on the border of the field and then distributed. To accomplish the water-slacking in a satisfactory manner, from 2 to 2½ pails of water should be sprinkled over each cask of lime as it is emptied upon the pile, and finally the whole mass should be very thoroughly covered with soil. In a few days practically all of the lime will be in a fine condition suitable for spreading. In loading it into the spreader care should be taken to first remove the soil, so as to avoid its clogging the machine. If the lime spreader itself is not fitted with a screen, the lime should first be carefully screened for the purpose of removing any hard lumps which may remain, due to imperfect slacking or burning. These lumps may be further slacked by themselves.

A practice preferred by many, and probably the most feasible one where a lime spreader is not to be had, is to place the burned lime in piles of from 40 to 50 pounds each at suitable intervals (heaps of 40 pounds each 2 feet apart in each direction equals 2 tons per acre), and cover the piles with moist earth. In a few days the lime is so thoroughly slacked that it can be spread directly with a shovel. Provided the soil is dry, from one-fourth to half a pail of water (or in extreme cases even more) should be sprinkled over each pile immediately before it is covered with earth. In this case, as in all others where slacked lime is employed, it is important that it be harrowed into the soil immediately after spreading. In no case should it be exposed long to the air before harrowing, or it is liable to cake and form a sort of mortar, to such an extent that it is impossible to mix it as thoroughly with the soil as before.

FORMS OF LIME USED FOR AGRICULTURAL PURPOSES.

Caustic ("quick" or "burnt") lime obtained by burning oyster shells, limestone, etc., is the most economical form in which lime can be bought, in all cases where railway transportation is great or the material must be carted long distances. One hundred pounds of such lime usually contains about 95 pounds of actual lime. Sometimes burned lime contains considerable magnesia, a point which has already been considered (p. 7).

According to Roberts, "when first removed from the kiln, lime weighs about 75 pounds to the heaped bushel; that from shells weighs less than that from limestone. A ton of limestone converted into caustic lime (CaO) weighs between 1,100 and 1,200 pounds; hence it is economy to burn the lime near where the stones are quarried, since it weighs but three-fifths as much as limestone. In slacking, lime takes up considerable quantities of water; hence a ton of slacked or hydrated lime contains really but three-fourths as much lime as a ton unslacked. A heaped bushel of unslacked lime makes 1½ bushels of slacked lime;[1] therefore it should be transported before it is slacked. When caustic lime is exposed to the air for some time it absorbs moisture and carbonic acid from the atmosphere, and becomes air-slacked or carbonate of lime ($CaCO_3$), or limestone. It is now in the form of a fine powder, much finer than ground limestone." Lime made from oyster shells and magnesian limestone weighs less per bushel than that made from the purer kinds of limestone.

Gypsum or land plaster is a combination of lime with sulphuric acid (oil of vitriol) and water. Upon heating, gypsum loses its water and is changed into plaster of paris or calcined plaster, which is used in making casts and for many other industrial purposes.

In case a soil is seriously deficient in lime, gypsum may act as a direct manure; usually, however, its beneficial effect upon soils is attributed to its indirect action in liberating potash, and possibly other elements, which were locked up in the soil in such combinations that plants could not make use of them. Gypsum may be helpful to a limited extent on clayey soils by flocculating the fine particles, on account of which the soil is less likely to become "water-logged" and to cake and interfere with the operations of tillage. In the last-mentioned respect water-slacked lime or that in the form of carbonate is said to be much more efficacious than gypsum, though as a liberator of potash gypsum is claimed to lead.

It is stated on good authority that, in the presence of decaying organic matter, gypsum may be changed into carbonate of lime. While this may be true under certain circumstances, in experiments at the Rhode Island Station on a soil exceptionally rich in humus and containing a moderate amount of plant residues which were undergoing decomposition, such a change did not result, if at all, to a prac-

[1] A bushel of air-slacked lime is usually considered to weigh 50 pounds.

tical extent. For this reason and on account of the fact that gypsum contains only about one-third as much lime as burned lime, and usually costs as much or more per ton, it can not take the place of the latter for most purposes where lime is applied to land.

For use in renovating "black alkali" (sodium carbonate) soils in the arid regions, gypsum, as already explained, performs a valuable function which can not be filled by any of the other forms of lime.

Chalk is a naturally occurring form of carbonate of lime which is exceptionally pure. It is quite soft, and is frequently referred to as marl.

Marl is a name which is applied to earthy deposits usually more or less friable in their character and containing carbonate of lime in quantities ranging usually from 5 to 95 pounds per 100 pounds of the material. It must be evident, therefore, that if one intends to make use of a given deposit of marl for the lime contained in it, he should first have a sample of it analyzed.[1] If the material will not effervesce upon the addition of vinegar, it probably contains but little carbonate of lime and may be of doubtful value. This test should precede, and not be substituted for, a careful chemical analysis.

On account of the varying chemical composition of marl, it must be obvious also that no definite rules as to the amounts which should be used in given cases can be stated. On a soil where one had reason to think a ton of burned lime should be applied per acre, about four tons of a marl containing from 20 to 25 per cent of actual lime (calcium oxid) should be employed. If the marl is twice as rich the amount applied should be but two tons, etc.

Marls vary somewhat in their physical characteristics, depending upon the amounts and character of the earthy material associated with the carbonate of lime. If the marl is associated with clay it is exceptionally well adapted for use on sandy soils, since the clay and carbonate of lime both tend to make such soils more compact and retentive of manures and moisture. A marl containing sand would, on the other hand, be better suited to clayey soils. According to Heinrich, sand marl may be applied to the soil immediately, but clay marls sometimes contain injurious compounds of iron and sulphur, in which case it is not safe to use them until they have been composted for two or three years, or long enough to effect the decomposition of the iron compounds.

Some so-called marls contain considerable quantities of phosphoric acid and potash in such forms as to greatly enhance their fertilizing value.

Phosphate of lime is found as bone, guano, apatite, and in the form of the well-known South Carolina, Florida, and Tennessee phosphate rock. The better classes of phosphate rock contain but small quantities of carbonate of lime, while others contain large amounts. The latter are unfitted on this account for superphosphate manufacture. Both classes

[1] The experiment stations in the different States would probably undertake to do this free of cost.

of phosphate when ground finely have been found to be effective upon acid soils, particular attention having been devoted to their employment on acid muck or peat soils. They not only seem to materially reduce the acid character of such soils, but after having been in contact with the soil for some time the assimilability of the phosphoric acid seems to become materially increased. The lower-grade phosphates containing considerable quantities of carbonate of lime are particularly effective upon acid soils.

In employing undissolved phosphate rock upon acid soils, good authorities recommend following the application of the phosphate at an interval of some months, or, if possible, a year, with a dressing of lime. This seems to be a reasonable recommendation in connection with certain plants which are indifferent to acid conditions.

Superphosphates, which are prepared by treating phosphate rock, bone, and boneblack with sulphuric acid. generally have about one-third of their lime combined with phosphoric acid and two-thirds with sulphuric acid. The lime combined with sulphuric acid is nothing more nor less than gypsum (land plaster). For this reason superphosphates frequently do not work as well on acid soil as ordinary undissolved phosphate rock or ground bone, and if, as is sometimes the case, a slight excess of sulphuric acid is present they may even exert an injurious action on soils devoid of carbonate of lime.

Basic slag (Thomas slag or slag meal) is a waste product obtained in the manufacture of steel. It contains relatively more lime than the ordinary high-grade phosphates, and the phosphoric acid in most cases (a few works have put an inferior product on the European market) is possessed of a high degree of assimilability. This product is as yet little known in this country, but if sold as cheaply as it might be it will doubtless prove of great value to our agriculture. It is an effective source of phosphoric acid for use upon all kinds of soils, and on account of its lime it is of special promise in the reclamation of exhausted acid soils, particularly such as are rich in organic matter, like many marsh or muck soils.

Unleached wood ashes contain about 35 pounds of actual lime (calcium oxid) in every hundred, three tons being, therefore, a little more than equivalent, in lime, to one ton of burned lime. They also contain from 5 to 7 per cent of potash, 1 to 2 per cent of phosphoric acid, and from 3 to 5 per cent of magnesia. This latter ingredient, though usually ignored, is, when not present in too great proportions, of approximately as much value as lime on acid soil. Magnesia is sometimes lacking in soils. When applied to such soils it seems to have a direct manurial action.

Leached wood ashes contain usually less than 1 per cent of potash and rather more lime than unleached ashes. Frequently they are sold in a wet condition, which of course lowers the quantity of actual lime present in a ton.

Limekiln ashes often contain approximately 40 per cent of lime, and when wood is employed in the burning instead of coal they sometimes contain 2 per cent or more of potash.

Finely ground limestone and oyster shells can be used to advantage, if obtainable, but they are not as efficacious as after burning, for the reason that they are not so active chemically, nor can they be reduced to so fine a state before burning as afterward.

Dye-house lime usually contains only a small percentage of lime, and if moist can not be transported long distances at a profit. A rule that applies well to this and all other waste products of a similar character is not to use them until they have been subjected to chemical analysis, for by changes in processes of manufacture their value may be materially influenced and substances injurious to vegetation may have found access to them.

Gas-house lime.—It is never safe to use this substance until it has first been allowed to weather for several months. On acid soils lime in this form is less effective than that in form of burned lime, wood ashes, and limekiln ashes. Owing to recent changes in the process of gas manufacture, lime is less used than formerly.

Waste lime from beet-sugar factories may be effectively applied to soils after it has been allowed to dry. It contains some potash, phosphoric acid, and nitrogen, which still further increases its value. If this material is applied to the soil in a wet condition, it tends to cake in the same manner as water-slacked lime does when not immediately worked into the soil. It is sometimes put in piles by itself and worked over every few weeks. It may also be dumped in the field during the winter in small piles, where it is allowed to remain until spring, when, after drying sufficiently, it may be spread and incorporated into the soil. According to Heinrich, this material contains: Water, 35 to 60 per cent; nitrogen, 0.1 to 0.4; potash, 0.1 to 0.3; phosphoric acid, 0.5 to 1.5, and lime, 15 to 30 per cent. It is evident that this waste material in its moist condition could not be transported to any considerable distance at a profit, and in this country, where labor is such an important item, it would not pay to shovel it over much in order to get it into condition to use.

Waste lime from soda-ash works usually contains considerable water, and can for this reason only be employed to advantage where the cost of transportation is small. If some economical means of drying it could be devised, the range of distance to which it could be profitably shipped would be much increased.

From the preceding statements regarding the different forms of lime used for agricultural purposes it is evident that it is impossible to state definitely for all locations and conditions which form is most economical to employ. The character of the soil and of the crop to be grown, as well as the market prices prevailing, must be taken into account, as well as the form of lime. Caustic or quicklime is the most

concentrated form, and consequently the most economical to handle. Its caustic properties, however, render it more vigorous in its action than the milder sulphate (gypsum) or carbonates (limestone, chalk, wood ashes, marl, etc.), and thus better suited for application to soils which are rich in organic matter than to poor soils deficient in this substance. For the same reason, however, it is especially suited to correcting acidity in sour soils. There may be special reasons in particular cases, however, why some of the other forms of lime are preferable to quicklime. Gypsum has been used to a considerable extent with very satisfactory results. On account of its peculiar composition it has been found especially valuable for neutralizing sodium carbonate (black alkali) in alkali soils. Wood ashes are extensively used in some localities, in many cases as much for the lime as for the potash which they contain. It is very doubtful, however, whether it would not be more economical, at the present prices of wood ashes and caustic lime, to employ the latter in the majority of cases, supplementing the lime with potash salts and other fertilizing materials if the latter are required by the soil.[1] The item of transportation is also decidedly in favor of the use of lime and fertilizer chemicals as substitutes for ashes.

SUMMARY.

The use of lime as a soil improver is very ancient, and its value for this purpose is generally recognized. Its action as a fertilizer is both direct and indirect.

There are many soils in which lime is deficient, notably in soils derived from granite, mica schist, and sandstone formations. On such soils lime is of direct value in supplying a necessary element of plant food.

The indirect value of lime is perhaps more important than its direct action, because probably the majority of cultivated soils contain sufficient lime to meet the direct demands of plants. Lime is of indirect value in unlocking the unavailable potash, phosphoric acid, and nitrogen in the soil.

Lime exerts a decided influence on the mechanical condition of soils, rendering heavy compact soils looser in texture and tending to bind particles of loose leachy soils.

Lime is also beneficial in furnishing conditions in the soil favorable to the activity of the micro-organisms which convert the nitrogen of organic matter into nitrates which are readily assimilated by plants, which decompose organic matter, and which assist leguminous plants to assimilate the free nitrogen of the air.

One form of lime, gypsum, has been shown to be a most effective corrective of black alkali, found in some of the soils of the arid portions of the United States.

The continued use of lime unaccompanied by other fertilizers may prove injurious, especially on poor soils, since it converts the insoluble

[1] U. S. Dept. Agr., Farmers' Bul. 65 (Experiment Station Work—II), p. 24.

nitrogen, potash, and phosphoric-acid compounds of the soil into forms which are rapidly taken up by plants or washed out in the drainage, and thus hastens the exhaustion of the supply of these substances in the soil. As the German adage states, "The use of lime without manure makes both farm and farmer poor." If the soil is not abundantly supplied with organic matter, its retentive power for water and fertilizers may be seriously reduced on account of the destruction of the organic matter by the action of too much lime. Soils are sometimes injured by applications of impure forms of lime, which harden like cement in the soil, or of those which contain an excessive amount of magnesia.

It has been shown that even many upland and naturally well-drained soils apparently in good condition otherwise are so sour (acid) that most plants will not thrive on them. The application of caustic lime is the most economical and effective means of correcting this condition. According to experiments made by the Rhode Island Experiment Station on acid soils in that State, the plants tested may be classified with regard to their behavior toward lime as follows: Plants benefited by liming—spinach, lettuce, beets (all kinds), gumbo (okra), salsify (vegetable oyster), celery, onion, parsnip, cauliflower, cucumber, eggplant, cantaloupe, asparagus, kohl-rabi, cabbage, dandelion, Swedish turnip, pepper, pea, peanut, martynia, tobacco, sorghum, alfalfa, clover, barley, wheat, oats, timothy, and Kentucky blue grass; plants injured by liming—serradella, watermelon, blue lupine, and common sorrel (*Rumex acetosella*); plants indifferent to liming—Indian corn, common millet, Hungarian, golden millet, rye, potatoes, carrots, Rhode Island bent (grass), and redtop (grass).

Lime may be applied in a variety of forms, among which are caustic, or burnt lime, or quicklime, which should contain at least 90 per cent of actual lime (CaO) and is the most concentrated form of this material; gypsum, or land plaster, in which the lime is in the form of the mild sulphate; ground limestone and chalk, in which the lime is in the form of the mild carbonate; different kinds of marl, containing varying proportions of sand and clay and from 5 to 95 per cent of carbonate of lime; wood ashes, which contain from 30 to 35 per cent of lime in the form of carbonate; limekiln ashes, containing about 40 per cent of lime; and waste lime from gas houses, sugar-beet factories, etc., the composition of which varies with the process of manufacture.

It is impossible to state definitely for all locations and conditions what form of lime is cheapest to use. Caustic, or quicklime, is the most concentrated form and consequently the most economical to handle. On account of its caustic properties it is more vigorous in its action than the milder sulphate (gypsum) or carbonates (limestone, chalk, wood ashes, marl, etc.). There may be special reasons, however, why some of the latter forms may be preferable. For instance, gypsum, on account of its peculiar composition, has been found to be a specially valuable corrective of black alkali.

The frequency with which liming should be practiced depends, among other things, upon the character of the soil and the rate of application, the number of years involved in the rotation practiced, the plants grown and their order of succession. As a general rule, it may be stated that from one-half to 1½ tons of lime per acre every five or six years is sufficient. Applications of two or three tons may, however, be advisable in case of very acid soils which are to be seeded down and to remain in grass for several years. The practice of applying small amounts of lime at somewhat frequent intervals is being generally accepted as preferable to the use of large amounts at rare intervals.

Lime in the form of carbonate of lime, as in marl, wood ashes, etc., can usually be applied with safety in the spring or at any other season of the year, but autumn is always the safest time to apply caustic or slacked lime. It is generally considered best to apply the lime to the soil immediately after plowing and harrow in thoroughly. Lime which is already slacked may be spread upon the soil directly from wagons or carts, or dumped into heaps and then spread with a shovel, although the most satisfactory plan in such cases is to use a lime spreader or ordinary grain drill with fertilizer attachment. Where a lime spreader or similar implement is not available the burnt lime may be placed on the soil in piles of from 40 to 50 pounds each, covered with moist earth, and allowed to slack before being spread with a shovel. Marls frequently contain injurious compounds and should therefore be allowed to weather for some time in the field before being incorporated with the soil. The same is true of gas-house lime, which is impregnated with sulphur compounds which are injurious to plants.

In conclusion it may be said, ascertain first whether lime is needed. If it is, apply it judiciously, and never depend upon lime alone to maintain the fertility of the soil, for all of the ingredients which plants need must be present in the soil to insure the profitable production of crops.

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